Investigation of Exposure Factors in Japanese Routine Mammography

Tatsuya Fujisaki[1)], Seiji Takahashi[2)], Kanako Watanabe[3)], Katsuyuki Nishimura[1)], Shinji Abe[1)], Hidetoshi Saitoh[4)], and Kenichi Fukuda[4)]

1) Department of Radiological Sciences, Ibaraki Prefectural University of Health Sciences
2) Department of Radiology, Center Institute Hospital, 3) Department of Radiology, Aomori City Hospital
4) School of Radiologic Sciences, Tokyo Metropolitan University of Health Sciences

Investigation of Exposure Factors in Japanese Routine Mammography

藤崎　達也[1)]　高橋　清治[2)]　渡辺可奈子[3)]
西村　克之[1)]　阿部　慎司[1)]　齋藤　秀敏[4)]
福田　賢一[4)]

この論文では，癌研究会附属病院において1,313名の女性を対象に1台の乳房撮影装置と1名の認定放射線技師によって撮影された，左・右および頭尾・内外側斜位方向の計5,252回の乳房撮影により得られた患者データと撮影データを報告する．

乳房X線画像や被曝線量は被検者の乳房形態や撮影条件に大きく依存するため，乳房撮影の最適化を図るためには，はじめに乳房撮影の現状を把握する必要がある．乳房撮影に影響する患者側の因子としては，年齢，圧迫乳房厚および圧迫圧，技術的な因子としては，ターゲット/フィルタの組み合わせ，管電圧および管電流時間積がある．そこで，これらのデータ取得を行い，各項目や各因子について統計的に整理・検討した．

各項目の平均値±標準偏差は，たとえば，1)年齢51±11歳，2)圧迫乳房厚43±12 mm，3)圧迫力8.4±2.2 kg重，4)管電圧28±1.8 kVおよび管電流時間積59±24 mAsであった．ターゲット/フィルタの組み合わせは，Mo/Mo83.8%，Mo/Rh15.0%およびW/Rh1.2%であり，Mo/RhやW/Rhの選択率は小さかった．圧迫乳房厚と圧迫力を撮影方向で検討し，圧迫力が頭尾方向のほうが約1 kg重小さく，圧迫乳房厚が頭尾方向のほうが約3mm大きくなるのは，撮影方向による圧迫面積の相違も原因であると思われた．すべてのターゲット/フィルタの組み合わせで撮影されていた60mmの圧迫乳房厚において，圧迫乳房厚と空気カーマの関係から，Mo/Moに対して，Mo/Rhは約10%，W/Rhは約60%の入射線量を低減できる可能性を示唆した．また，加齢によって乳腺が脂肪に置換されることから，年齢が増加するほど圧迫しやすい傾向が示され，比較的乳房撮影が多く行われる40-65歳では，入射線量の年齢依存性がほとんどないことを示した．

***Research Code No.:** 521 (Breast), 204.1 (diagnostic X-ray unit, general)*

***Key words:** Mammography, Patient factor, Exposure factor*

Received Feb. 16, 2001; revision accepted Jun. 14, 2001

1) 茨城県立医療大学保健医療学部放射線技術科学科
2) (財) 癌研究会附属病院放射線診断科
3) 青森市民病院診療放射線部
4) 東京都立保健科学大学保健科学部放射線学科

別刷請求先
〒300-0394　茨城県稲敷郡阿見町阿見4669-2
茨城県立医療大学　放射線技術科学科
藤崎　達也

Introduction

The prevalence of mammography in Japan has grown in response to the increased incident of breast cancer[1)]. Mammography is employed for early detection of breast cancer because it provides a more precise diagnosis than palpation[2)].

However, mammography is accompanied by radiation exposure to the breast, which is regarded as a comparatively radiosensitive organ[3)]. In order to optimize mammography in terms of both diagnostic accuracy and patient exposure, mammography procedures need to be examined in detail in order to identify the conditions for obtaining the highest image quality with the lowest radiation dose. Compressed breast thickness and exposure settings are the major factors influencing the absorbed dose to the breast. Although many radiologic technologists have recently been certified as mammoscreeners (MRT) by the Japanese Society of Radiological Technology (JSRT), there has been little research conducted by such certified individuals concerning the evaluation of mammography procedures. Young et al. reviewed mammography screening in detail in the United Kingdom[4)]. The mean glandular doses for mammographic screening were particular reported routinely at screening centres in the UK Breast Screening Programme (NHSBSP).

Exposure factors for optimum mammography condition, defined here in terms of image quality and patient exposure, are considered to be largely dependent on both patient and technical factors[5)]. As such, we statistically analyzed these factors as variables to be used for optimization. The patient factors investigated were age, projection, compressed breast thickness and degree of compression. The technical factors investigated were target/filter combination, tube voltage and tube loading. These factors were classified and analyzed, allowing the mean value, standard deviation and correlation of factors to be derived.

The present research involves an investigation of exposure factors and a comparison of the findings with previously reported results in order to provide data that may be useful for the improvement of routine mammography in Japan.

Materials and Methods

The study population consisted of 1,313 women who had a routine mammography taken with craniocaudal (CC) and mediolateral oblique (MLO) projections for each breast. The minimum and maximum age in this study were 15.2 years and 83.5 years, respectively. We used a mammographic X-ray unit (Mammomat 3000, Siemens) operated by a specific MRT from November 1998 to January 1999 at the Cancer Institute Hospital.

The inverter mammographic unit generates high-voltage waveforms with less than a 10% ripple. The unit is equipped with a molybdenum (Mo)/tungsten (W) dual track X-ray tube with external filters of 0.030 mm Mo, 0.025 mm rhodium (Rh) and 0.050 mm Rh. The available target/filter combinations are a Mo target with 0.030 mm Mo (Mo/Mo), a Mo target with 0.025 mm Rh (Mo/Rh) and a W target with 0.050 mm Rh (W/Rh). The unit featured the following: 1) a source-to-image distance (SID) of 60 cm; 2) a reciprocating grid ratio of 4:1 with a density of 27 lines/cm; 3) automatic exposure control (AEC) with a D-shaped detection area of 3×6 cm. The compression technique was applied for all women examined. The film/screen system used was a MinR2 screen (Kodak)/UM-HC film (Fujifilm) combination with a film size of 18×24 cm.

Mammographic positioning for all the women was done by one MRT using the standard criteria set by the JSRT[6], and the following data was recorded: patient data; age, projection, compressed breast thickness and compression force, and technical data; target/filter combination, tube voltage and tube loading. The target/filter combination and tube voltage were manually selected by the MRT so as to obtain the mammogram at 20 to 100 mAs, because longer exposure times result in larger doses according to the film non-reciprocity law and blurring due to patient movement. In addition, the change of shapes of the X-ray spectrum was set in order to small. The above is based on MRTs experience. The decision concerning tube loading was determined by AEC automatically. The average optical density of the area of the main glandular tissue on a mammogram was about 1.3 under the above conditions. The AEC was adjusted to and tested daily at an optical density of 1.3 on the RMI-156 phantom.

The degree of compression was subjectively judged by the MRT according to patient age, shape, and presumed internal anatomy of the breast by palpation. Compressed breast thickness (in mm) and compression force (in kgw) were read directly from the digital display on the unit. An initial calibration of the compression device was performed using a 10 mm thick PMMA phantom and an analog bathroom scale according to recommendations[7]. The accuracy of the compressed breast thickness and the compression force were estimated to within 1 mm and 1 kgw, respectively. Exposure data obtained under AEC conditions were recorded. The incident air kerma to the compressed breast for an exposure was calculated using a Spectrum Processor[8].

All data were imported into computer software (Microsoft Excel, Microsoft) and statistical analyses were performed using other software (Atatistic Analysis System (SAS), SAS Institute).

Results

Figure. 1 shows a histogram of the age distribution of Japanese women (A) and the ratio of women who have had a mammography examination (B) in this study. Figure. 1 (B) is shown as the ratio of the normalized age distribution of women who have had a mammography examination calculated from Fig. 1 (A) to the normalized age distribution of women in Japan. The latter is calculated from the official statistical population given by the Statistics Bureau and Statistics Center of the Management and Coordination Agency of Japan. The age distribution of women examined was represented by a normal distribution with 51±11 years.

A histogram of the compressed breast thickness distribution and the compression force distribution for each projection are shown in Fig. 2. The compressed breast thickness distribution was a normal distribution centered around approximately 40 mm; the mean for CC was 44.1 mm, and the mean for MLO was 41.2 mm for both the right and left breasts, 42.6 mm for the right breast (R) and 42.7 mm for the left breast (L) in two projections. The compressed breast thickness for CC was significantly greater than MLO ($p<0.001$, paired t test), and there was no difference between R and L. The distribution of compression force was also a normal distribution with a mean of 7.9 kgw for CC and 9.0 kgw for MLO. The compression force for MLO was significantly greater than CC ($p<0.001$, paired t test), and there was no difference between R and L.

Figure. 3 shows the mean compressed breast thickness for each projection as a function of compression force (A) and mean compression force for each projection as a function of compressed breast thickness (B). The compression force and compressed breast thickness were classified in each interval, and the mean value and 95 % confidence limits were calculated. The error bars indicate the 95 % confidence limits. The mean compressed breast thickness for CC was larger than for MLO at any compression force, and the mean compression force for MLO was greater than CC at any compressed breast thick-

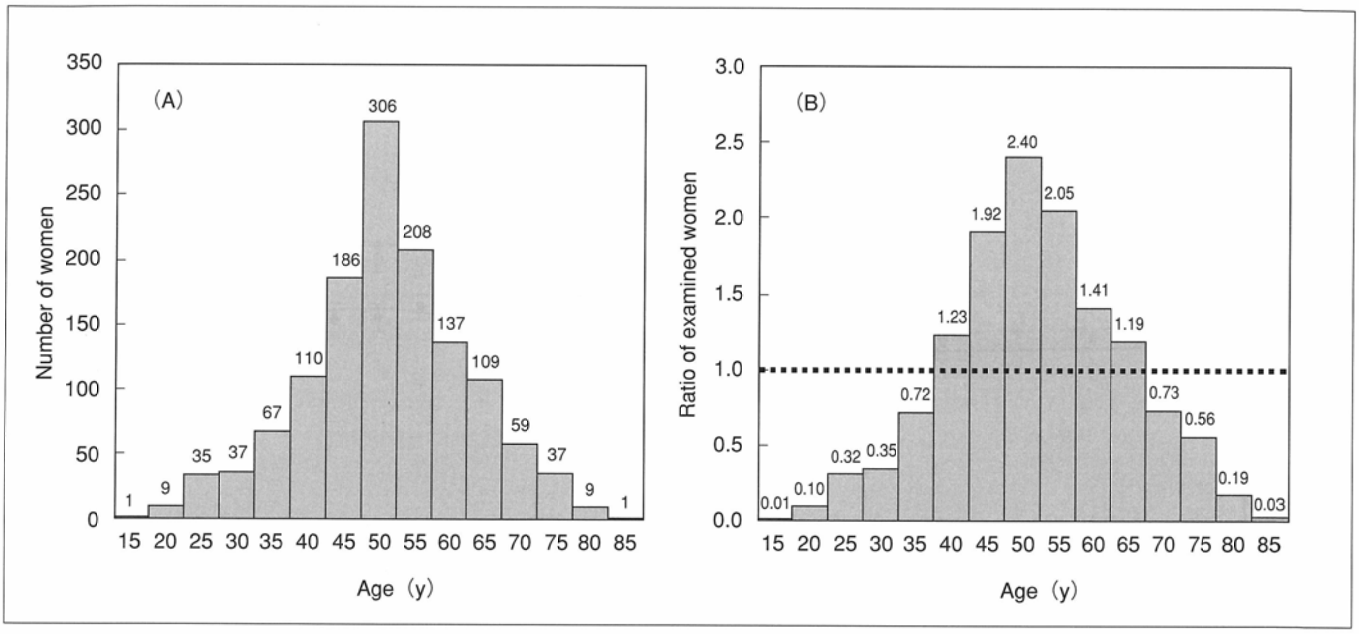

Fig. 1 Histogram of age distribution of 1,313 women examined. Axis labels represent the mid-point of 5 year intervals.
A: Number of women plotted against age.
B: Ratio of examined women plotted against age, given as a ratio of the normalized age distribution in (A) to the normalized age distribution of women in Japan (official statistical population given by the Statistics Bureau and Statistics Center of the Management and Coordination Agency of Japan).

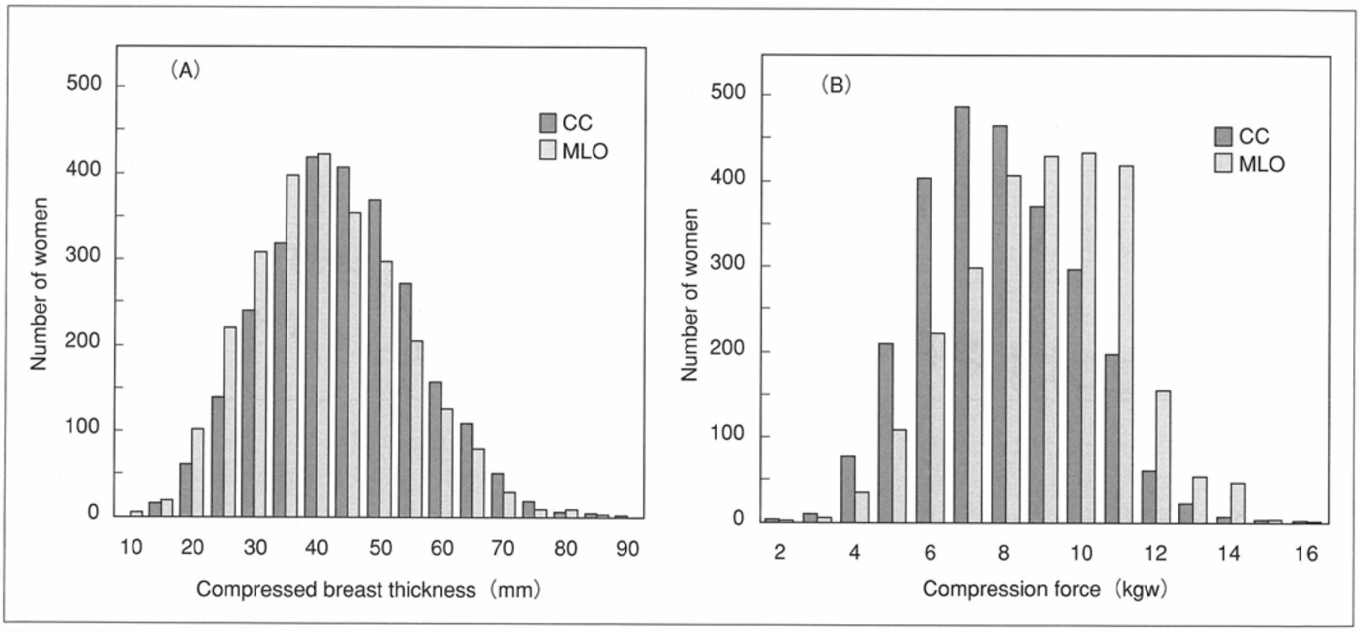

Fig. 2 Histogram of compressed breast thickness (A) and compression force (B) determined for CC and MLO projections. Each axis label represents the mid-point of 5 mm and 1 kgw intervals, respectively.

ness. The relationship between compressed breast thickness and compression force was not expressly indicated.

The mean compressed breast thickness and mean compression force for each projection as a function of age are shown in Fig. 4. The mean compressed breast thickness and mean compression force were grouped in 5 year intervals, and mean value and 95 % confidence limits were calculated. The error bars indicate the 95 % confidence limits. The mean compressed breast thickness can be seen from Fig. 4 (A) to reach a peak at 60-65 years, and be lowest at 25-30 years. The mean compressed breast thickness increased gradually in the age range 30-65 years. The mean compression force also increased gradually with age, as shown in Fig. 4 (B).

The selected target/filter combinations and tube voltages are shown in Fig. 5 as a function of compressed breast thickness. Fig. 5 (A) shows the selected ratio of the target/filter combination as a function of compressed breast thickness. The selected counts were classified in 5 mm intervals, and the

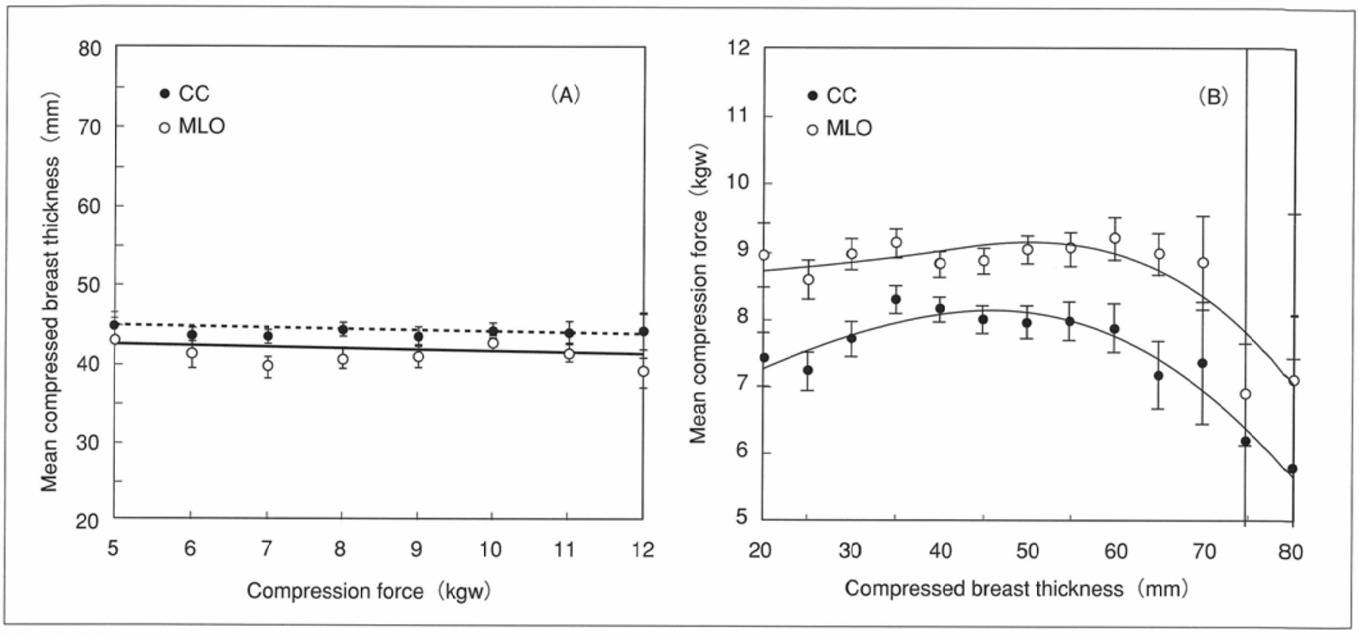

Fig. 3 Mean compressed breast thickness for each projection as a function of compression force (A) and mean compression force for each projection as a function of compressed breast thickness (B). Each axis labels represents the mid-point of 1 kgw and 5 mm intervals, respectively, and error bars indicate 95 % confidence limits.

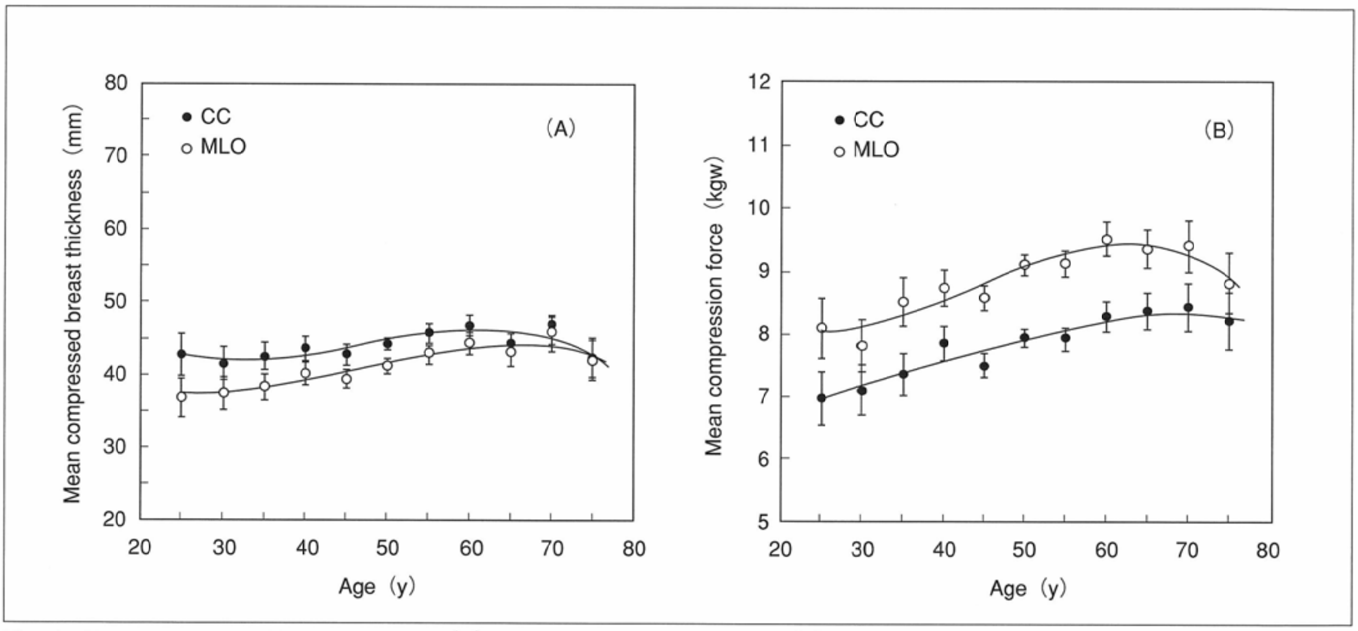

Fig. 4 Mean compressed breast thickness (A) and mean compression force (B) for each projection as a function of age. Each axis labels represents the mid-point of 5 years intervals, and the error bars indicate 95 % confidence limits.

selected ratio was calculated. The target/filter combination selected was Mo/Mo for 83.8 % of cases, Mo/Rh for 15.0 % of cases and W/Rh for 1.2% of cases. Fig. 5 (B) shows the mean tube voltage for each target/filter combination as a function of the compressed breast thickness. The tube voltage was classified in 5 mm intervals, and the mean value and 95 % confidence limits were calculated. The error bars indicate the 95 % confidence limits. The mean tube voltage increased with compressed breast thickness in a manner dependent on the target/filter combination, as shown in Fig. 5 (B).

The incident air kerma for each target/filter combination is shown as a function of compressed breast thickness and age in Fig. 6. The incident kerma was classified in each interval, and the mean value and 95 % confidence limits were calculated. The error bars indicate the 95 % confidence limits. The incident air kerma increased with compressed breast thickness, dependent on the target/filter combination, as shown in Fig. 6 (A). However, the incident air kerma exhibited no significant increase with age as shown in Fig. 6 (B).

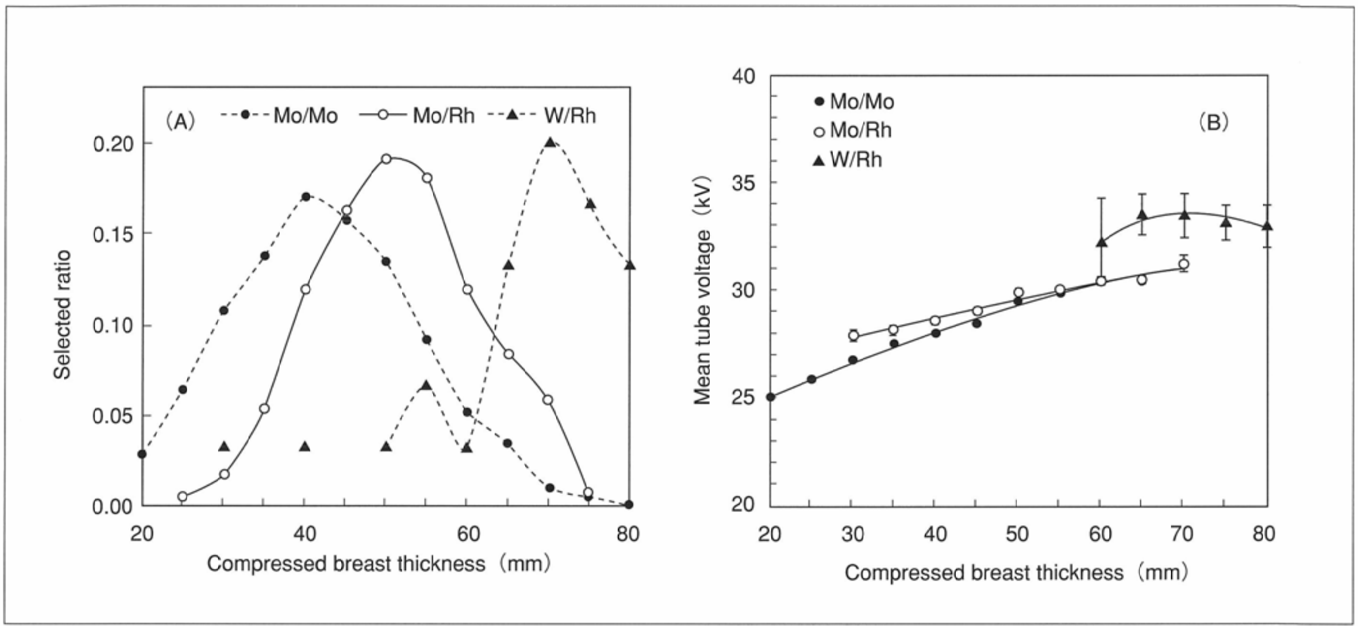

Fig. 5 Selected ratio of target/filter combination (A) and mean tube voltage for each target/filter combination (B) as a function of the compressed breast thickness (B). Each axis label represents the mid-point of 5 mm intervals, and the error bars indicate 95 % confidence limits.

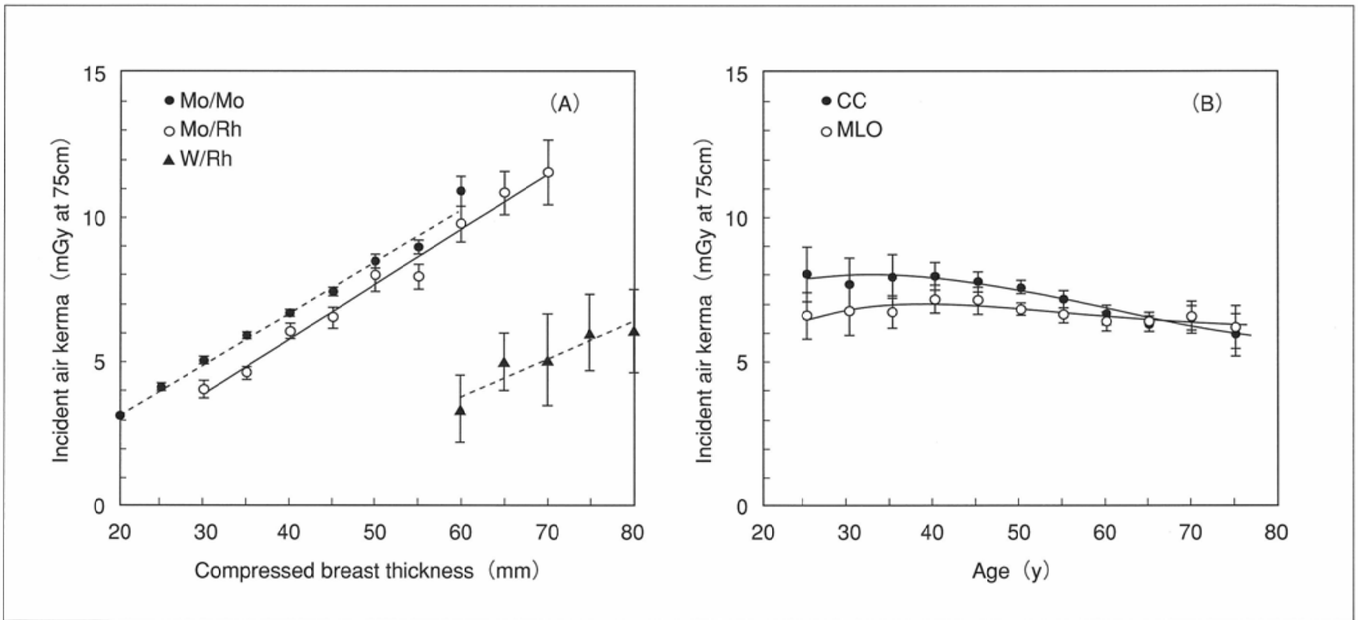

Fig. 6 Incident air kerma per target/filter combination as a function of compressed breast thickness (A) and age (B). Each axis label represents the mid-point of 5 mm and 5 years intervals, respectively, and the error bars indicate 95 % confidence limits.

Discussion

The mean age of examined women in this study was 51.3 years, which is similar to the mean age considered in other studies[4, 9–11]. Women of this age are most likely to undergo a mammography examination because the peak age cohort for breast cancer mortality in Japan is in 50s[1].

The mean compressed breast thickness for CC was about 3 mm thicker than for MLO. The mean compressed breast thickness has previously been reported for Japan as follows; 33.3 mm for MLO and 33.0 mm for CC[10], or 38.2 mm for CC[12], and 37.7 mm average according to the two projections[9]. In the UK, the reported values are 54.3 mm for MLO and 51.5 mm for CC[4], and in the USA, the reported thickness are 48 mm for MLO and 44 mm for CC[11], or 52 mm average for two projections[13]. The mean compressed breast thickness for MLO has been shown to be significantly greater than the thickness for CC in a number of studies[4, 9, 11], which is in contrast to the results of the present study. The mean compressed breast thickness seems to be dependent on individual MRTs or on the policy of the facility where the exam is carried out rather than anatomical differences.

The compression force for MLO was about 1 kgw greater than for CC, which is consistent with findings reported in another study[11]. The ratio of mean compression force to the mean compressed breast thickness[11] was significantly greater for MLO than for CC; 0.217 kgw/mm for MLO and 0.179 kgw/mm for CC. The value reported in the USA is 0.198 for MLO and 0.199 for CC[11]. It is somewhat more difficult for MRTs to compress the breast for CC than for MLO projection, because Japanese women have smaller breasts than many Western women. This is reflected in a greater compressed area for MLO than for CC in Japanese women, suggesting that a phantom of a human breast is needed. The compressed breast thickness is independent of compression force, as shown in Fig. 3, suggesting that MRTs effectively gain accurate knowledge of the optimum compression force for each projection through experience. The compressed breast thickness is related to age, as shown in Fig.4, which is tendency that has also been reported by Matsumoto et al[9].

The target/filter combinations selected were Mo/Mo for breasts with thickness less than 50 mm, Mo/Rh for breast of 50 to 60 mm thickness, and W/Rh for breasts larger than 60 mm thickness, as shown in Fig. 5. The Mo/Mo combination was used more often in the present study compared to other studies[4], which again is considered to be attributable to the smaller compressed breast thickness of Japanese women compared to women in Western countries. The selected ratio distribution of Mo/Mo and Mo/Rh are almost coincident, as shown in Fig. 5 (A). This is thought to be due to the lack of discrimination by the MRT in regard to the target/filter combination in the 50 mm breast thickness range. However, further studies on the best target/filter combinations appear to be necessary.

The incidence air kerma was calculated directly from its proportionality to the surface entrance dose, which in turn correlates to the average glandular dose. As breast tissue composition was not investigated, the average glandular dose was not calculated. The incidence air kerma data was obtained at a distance of 75 cm from the target and calculated using a Spectrum Processor[8], and was used primarily for the comparison of target/filter combinations. The calculated mean incident air kerma was 7.0 mGy per exposure at 75 cm distance in this study. The incident air kerma necessary for exposing the compressed breast thickness of 60 mm was estimated to be about 10 % less for Mo/Rh and about 60 % less for W/Rh compared to Mo/Mo. Hence, the use of Mo/Rh in preference to Mo/Mo dose not provide any considerable reduction in exposure, as shown in Fig. 6 (A). The improvement of materials and thickness of the filter and grid radiography for thinner breasts for Japanese women and related issues should be further discussed. The lowest exposure was achieved through when using the W/Rh combination. W/Rh has better performance for thicker breasts due to the narrower spectrum through the breast compared to the other target/filter combinations[14]. W/Rh is therefore an appropriate choice for thicker breasts. The incident air kerma decreased gradually with age, becoming constant in the range 40-65 years. The change of tissue glandularity with age is well known. The change in incident air kerma with age is considered to be due to a reduction of glandular tissue and an increase of adipose tissue. This is supported by the observation that compressed breast thickness increases with age in the range 40-65 years, as men-tioned previously. This age dependency of incident air kerma can also be explained by the age dependency of compression force.

Conclusion

This study involved 1,313 women who had been examined by mammography using a mammographic unit operated by one MRT during a 3-month period at the Cancer Institute Hospital in Japan. The exposure factors for optimum mammography conditions are considered to be dependent on variables of both patient and technical factors. The patient factors investigated were age, projection, compressed breast thickness and degree of compression, and the technical factors investigated were target/filter combination, tube voltage and tube loading. These factors were classified and analyzed statistically, involving the examination of the mean, standard deviation and correlation of factors. The findings of this study are as follows:

1. Although the compressed breast thickness for CC was 7 % larger than for MLO, the compression force for MLO was about 1 kgw greater than for CC. The reason for this originates from the fact that the compressed breast area for MLO is greater than for CC projection.
2. The incident air kerma was 10% less for Mo/Rh and 60 % less for W/Rh compared to Mo/Mo at a compressed breast thickness of 60 mm. Although the dependence of image quality on the target/filter combination was not examined in this study, the W/Rh was found to permit significant dose reductions for thicker breasts.
3. The incident air kerma remained almost constant in the 40-65 year age range. It was concluded that the variation of incident air kerma according to age results from a reduction of glandular tissue and corresponding increase of adipose tissue.

References

1) Kido C and Kuroishi T: Present situation and problems on imaging of breast cancer screening in Japan. Nichidoku-iho 40: 467–480, 1995 (in Japanese)

2) Ohuchi N, Yoshida K, Kimura M, et al: Improved detection rate of early breast cancer in mass screening combined with mammography. Jpn J Cancer Res 84: 807-812, 1993

3) National Council on Radiation Protection and Measurements (NCRP): Mammography - A User's Guide. NCRP report 85. 1986, NCRP, Maryland

4) Young KC and Burch A: Radiation doses received in the UK Breast Screening Programme in 1997 and 1998. Br J Radiol 73: 278–287, 2000

5) Wentz G: Mammography for Radiologic Technologists. 2nd edition. 1996, McGraw-Hill, Tokyo

6) Radiography subcommittee, Japanese Society of Radiological Technology (JSRT): Mammographic Quality Control Manual (revised edition). JSRT, 1999, JSRT, Kyoto (in Japanese)

7) Committee on quality assurance in mammography, American College of Radiology (ACR): mammography quality control. 1992, ACR, USA

8) The Institute of Physics and Engineering in Medicine (IPEM): Catalogue of X-ray spectra and other data. IPEM report 78 (electronic version). 1997, IPEM, England

9) Matsumoto M, Nishizawa K, Akiyama Y, et al: The mean breast thickness for Japanese patients for use in estimating the glandular dose in mammography. J Jpn Assoc Breast Cancer Screen 9: 95–102, 2000 (in Japanese)

10) Kon M, Osanai T, Ootani Y, et al: A study on compressed breast thickness in Hirosaki University Hospital. JARST 47: 653–659, 2000 (in Japanese)

11) Helvie MA, Chan HP, Adler DD, et al: Breast thickness in routine mammograms: Effect on image quality and radiation dose. Am J Roentgenol 163: 1371–1374, 1994

12) Fujisaki T and Kumagai Y: A study on average glandular dose using various compressed breast models. J Jpn Assoc Breast Cancer Screen 6: 291–298, 1997 (in Japanese)

13) Geise RA and Palchevsky A: Composition of mammographic phantom materials. Radiology 198: 347–350, 1996

14) Desponds L, Depeursinge C, Grecescu M, et al: Influence of anode and filter material on image quality and glandular dose for screen-film mammography. Phys Med Biol 36: 1165–1182, 1991